JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 9, Number 1 (October 2021):3107-3114, doi:10.15243/jdmlm.2021.091.3107
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Carbon storage and energy production of *Eucalyptus urophylla* developed in dryland ecosystems at East Nusa Tenggara

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Article history:

Received 9 July 2021
Accepted 30 July 2021
Published 1 October 2021

Keywords:

calorific value
carbon emissions
climate change mitigation
natural resources
renewable energy

Abstract

The development of *Eucalyptus urophylla* in dryland ecosystems plays an important contribution to support climate change mitigation and renewable energy diversification. However, the information about the potential of *E. urophylla* for carbon reduction and energy production is rarely documented, even though it is necessary as fundamental considerations to determine the best strategy for sustainable natural resources management, primarily in dryland ecosystems. This study aimed to quantify the carbon storage and energy production of *E. urophylla* established in dryland ecosystems at East Nusa Tenggara. The study site is located in a eucalyptus plantation managed by Timor Tengah Selatan Forest Management Unit. Destructive sampling was conducted on 25 sample trees that were evenly distributed from small to big ones. The percentage of carbon content in every tree component, namely stem, branch, and foliage, was determined using elemental analysis, while the calorific value of each tree component was analyzed using a bomb calorimeter. Carbon storage in each component was calculated by multiplying biomass and the percentage of carbon content, while the energy production was computed by multiplying high heating value and biomass from every tree component. The results found the mean carbon storage of *E. urophylla* in the study site was 55.51 kg tree^{-1} with a minimum of 6.34 kg tree^{-1} and a maximum of 184.76 kg tree^{-1}. The percentage of carbon content in the foliage was lower than other tree components by approximately 34.1%. Interestingly, the calorific value of foliage was relatively higher than stem and branch with around 5,252 kcal kg^{-1}. The energy production of *E. urophylla* ranged from 252.6 to 7,813.3 MJ tree^{-1} with an average of 2,357.87 MJ tree^{-1}. According to the results, this study concluded the development of *E. urophylla* in dryland ecosystems demonstrated a meaningful contribution to carbon absorption and energy production at East Nusa Tenggara.

To cite this article: Sadono, R., Wardhana, W., Idris, F. and Wirabuana, P.Y.A.P. 2021. Carbon storage and energy production of *Eucalyptus urophylla* developed in dryland ecosystems at East Nusa Tenggara. Journal of Degraded and Mining Lands Management 9(1):3107-3114, doi:10.15243/jdmlm.2021.091.3107.

Introduction

The management of dryland ecosystems currently becomes the most important issue in tropical countries, including Indonesia. Besides being expected to provide economic benefits, the activity of dryland ecosystems management is also targeted to reduce carbon emissions in the atmosphere and support renewable energy development (Yirdaw et al., 2017). To answer these challenges, the establishment of plantation forests using fast-growing species can become a realistic solution to optimize the potential of dryland ecosystems for economic improvement, climate change mitigation, and energy diversification (Stavi, 2019). However, this strategy is not easy to implement since it is highly difficult to find species that have good adaptability to dry conditions. Every species will generate detrimental growth performance if it is not tolerant to drought stress (Amissah et al., 2015). Considering the condition, it is essential to develop species that has good tolerance to dryland ecosystems. Among many tree species, *Eucalyptus urophylla* can become an alternative plant to support plantation forest development in dryland ecosystems. *E. urophylla* is a native species from Indonesia that is naturally distributed in dryland ecosystems at East Nusa Tenggara (Sadono et al., 2020). This plant is classified as fast-growing species with a straight stem and dense canopy (Yu et al., 2019). It also had a good tolerance to a wide range of environmental conditions (Saadaoui et al., 2017). Several studies report *E. urophylla* can grow well in a dry and wet environment with an altitude of 100-2,000 m above sea level (Zhang et al., 2015; Sumardi et al., 2016; Sadono et al., 2021). This species can survive in alkaline and acid soils with an acidity level of 5-7 (Lu et al., 2020; Sadono et al., 2021). In several countries, *E. urophylla* has been widely developed as the main species of plantation forests like Brazil, China, and Vietnam (Viera and Rodríguez-Soalleiro, 2019; Wang et al., 2019; Cuong et al., 2020).

Besides resulting timber forest products, this species also generates non-timber forest products from its leaves (Pujiarti et al., 2018). Several studies evidence that the leaves of *E. urophylla* contain essential oils (1,8-cineole) that are highly required for pharmacy industries (Traoré et al., 2010; Sebei et al., 2015; Pujiarti and Kasmudjo, 2016; Zhou et al., 2021). In addition, this plant also plays meaningful roles in ecological aspects. For example, the establishment of *E. urophylla* for reforestation program can accelerate the land cover process; thus, it has the potential to reduce the risk of soil degradation due to the impact of runoff and erosion (Oliveira et al., 2013; Raj et al., 2016; Thompson et al., 2016). *E. urophylla* is also well known as a plant species that provide a meaningful contribution to support climate change mitigation and renewable energy development since it has rapid growth and short rotation (Ferreira et al., 2017; Hernández-Ramos et al., 2017; Wirabuana et al., 2021). The development of *E. urophylla* in dryland ecosystems is still limited. In Indonesia, *E. urophylla* is only intensively managed in Timor Island, one of the regions at East Nusa Tenggara (Sadono et al., 2020). Besides becoming its natural habitat, this area is also categorized into dryland ecosystems with long dry periods and low rainfall intensity (Kalima et al., 2019). Unfortunately, the potential of *E. urophylla* from this site is rarely documented, mainly related to its contribution to climate change mitigation and renewable energy development. Therefore, this study aimed to quantify the carbon storage and energy production of *E. urophylla* developed in dryland ecosystems at East Nusa Tenggara. The outcomes will provide meaningful information for managers to consider the best strategy for supporting natural resources and environmental management in dryland ecosystems in the scope of economic improvement, carbon reduction, and energy diversification.

Materials and Methods

Study site

The study area is located in the *E. urophylla* plantation managed by Timor Tengah Selatan Forest Management Unit. It is situated in Timor Tengah Selatan District, approximately 180 km at the northeastern of Kupang. The study location has geographic coordinates in S9°50′0″ to S9°50′15″ and E124°15′30″ to E124°16′0″ (Figure 1). The total area of *E. urophylla* plantation in the study site is 25 ha. Altitude reaches 800 m above sea level (asl). The topography was predominantly by hilly area with slope level of 15-45%. Soil type is classified into cambisol with high cation exchange capacity. Annual rainfall reaches 1,500 mm year^{-1}. The mean daily temperature is about 29 °C with a minimum of 23 °C and a maximum of 30 ºC. Before being converted to *E. urophylla* plantation, the vegetation cover in this area was predominantly by *Imperata cylindrica* (Sadono et al., 2020). In 1997, the local government conducted reforestation using *E. urophylla* as the primary species for rehabilitation. Besides having rapid growth, *E. urophylla* is a native species from this location (Almulqu et al., 2019). Therefore, the activity of reforestation is also directed to support plant conservation from East Nusa Tenggara.

Data collection

This study was the next stage of research conducted by Sadono et al. (2020) that evaluated the productivity of *E. urophylla* in dryland ecosystems at East Nusa Tenggara. Different from the previous research, this study explored the potential of carbon storage and energy production in *E. urophylla* at the individual tree level. Data collection was implemented step by step in a chronological manner. It consisted of three important stages, i.e. destructive sampling, carbon content analysis, and energy estimation. Destructive sampling was conducted on 25 samples trees. Those trees were determined by considering their diameter distribution to obtain the balance growth dimension from small to big trees. In this context, we used the previous forest inventory data from Sadono et al. (2020). To facilitate this stage, we classified trees diameter into four categories, namely <10 cm, 11-15 cm, 16-20 cm, >20 cm (Sadono et al., 2021).

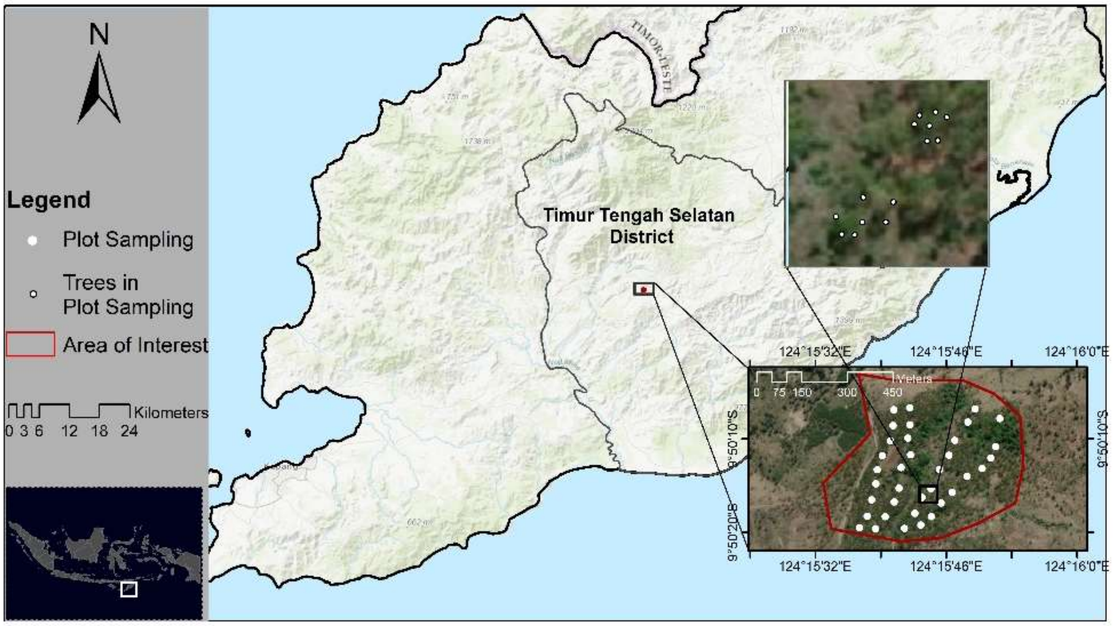

Figure 1. The study site of *E. urophylla* plantation in dryland ecosystems at East Nusa Tenggara. The white circle indicated the plot coordinates for forest inventory.

Every sample tree was felled using a chainsaw at the stump height of 0.1 m from above ground (Lu et al., 2018). Then, the tree components were separated into stem, branch, and foliage. The fresh weight of every component was measured using a hanging balance in the field with an accuracy of 0.1 kg. Afterwards, around 500 g sub-sample from each part was brought to the laboratory for drying (Wirabuana et al., 2020). The drying process was done using an oven at 70 °C for 48 hours before being weighted for biomass determination (Hakamada et al., 2017; Wirabuana et al., 2021). Total biomass in every tree component was quantified by multiplying the ratio of dry-fresh weight from the sub-sample with the total fresh-weight of each component from field measurement (eq.1). Meanwhile, total above-ground biomass at the individual tree level was calculated by summing the biomass from every tree component (eq. 2).

$$W_c = \left(\frac{FW_c}{FW_s}\right) DW_s \quad (1)$$

$$W_t = W_s + W_b + W_f \quad (2)$$

wherein W_c indicates biomass of tree component (kg), FW_c is fresh weight of tree component (kg), FW_s is fresh weight of sub-sample component (g), DW_s signifies dry weight of sub-sample component (g), W_t is total above-ground biomass at the individual tree level, and W_s, W_b, W_f indicates biomass accumulation in stem, branch and foliage.

After finishing the biomass determination, the subsample of every tree component was converted into flakes. Then, the flakes were divided into 2 parts with equal proportions for facilitating carbon and calorific value analysis. The dry weight of flakes from each part was recorded before starting the analysis process. In this study, the carbon content was determined by the elemental analysis method (Sato et al., 2014), while the calorific value was quantified using the bomb calorimeter method (Ju et al., 2016). Next, the ratio of carbon element from every component was multiplied with the biomass from tree components to determine total carbon stock in stem, branch, and foliage (eq. 3). Total carbon storage at the individual tree level was calculated by summing the carbon stock from each tree part (eq. 4). Meanwhile, the energy production was calculated by multiplying the calorific value of every tree component with their biomass accumulation (eq. 5). Thereby, total energy potential at the individual tree was quantified by summing the energy production from stem, branch, and foliage (eq. 6)

$$C_a = W_c \,.\, C_c \quad (3)$$

$$C_t = C_s + C_b + C_f \quad (4)$$

$$E_p = CV.W_c \quad (5)$$

$$E_t = E_s + E_b + E_c \quad (6)$$

wherein C_a is carbon stock in every tree component (kg), C_c indicates the percentage of carbon content in biomass (%), C_t represents total carbon storage at the individual tree level, C_s, C_b, C_f is carbon stock distribution in stem, branch, and foliage, CV shows a calorific value in every tree component (kcal kg^{-1}), E_p is total energy storage in each tree component (MJ), E_t is total energy production at the individual tree level, and E_s, E_b, E_c signifies energy stock in stem, branch, and foliage.

Data analysis

Statistical analysis was processed using R software version 4.0.2 with a significant level of 5%. The MASS package was selected to support the data analysis. A descriptive test was applied to identify the data attributes, i.e. minimum, maximum, mean, and standard deviation (Mishra et al., 2019). The normality of data was evaluated using the Shapiro-Wilk test (Ghasemi and Zahediasl, 2012). The homogeneity of variance from the relative contribution of every tree component to carbon storage and energy production among diameter classes was examined by Bartlett's test (Beyene, 2016). Then, the comparison means of relative contribution from every tree component to carbon storage and energy production at the individual tree level among diameter classes was tested using ANOVA followed by HSD Tukey (Arora et al., 2014).

Table 1. Summary statistics of destructive sampling for 25 sample trees of *E. urophylla* in the study location.

Parameter	Unit	Min	Max	Mean	SD
Individual tree dimension					
Diameter	cm	6.80	25.89	16.00	4.73
Height	m	13.40	34.41	23.78	5.28
Volume	m^3 $tree^{-1}$	0.02	0.87	0.28	0.20
Above-ground biomass					
Stem	kg $tree^{-1}$	12.68	411.94	118.76	92.65
Branch	kg $tree^{-1}$	0.53	9.73	4.01	2.70
Foliage	kg $tree^{-1}$	0.45	11.19	4.23	2.77
Total	kg $tree^{-1}$	13.66	420.97	127.00	95.49
Carbon Storage					
Stem	kg $tree^{-1}$	5.96	181.25	52.38	40.54
Branch	kg $tree^{-1}$	0.23	4.38	1.71	1.20
Foliage	kg $tree^{-1}$	0.14	3.47	1.43	0.90
Total	kg $tree^{-1}$	6.34	184.76	55.51	41.59
Energy Production					
Stem	MJ $tree^{-1}$	232.70	7635.24	2192.38	1710.08
Branch	MJ $tree^{-1}$	9.65	177.79	72.79	49.08
Foliage	MJ $tree^{-1}$	10.20	243.37	92.69	60.16
Total	MJ $tree^{-1}$	252.56	7813.30	2357.87	1768.39

Results and Discussion

Selected samples of trees

Summarized results of the observation indicated the majority of sample trees occupied the diameter class of 16-20 cm (Figure 2). Meanwhile, the lowest number of sample trees was recorded at the diameter class of >20 cm by approximately 4 trees. Overall, the distribution of sample trees for destructive measurement followed a normal distribution that was indicated by a bell curve pattern. It also confirmed that the selection of sample trees had represented the growth variation of *E. urophylla* at the study site. In the context of the destructive method, a representative sample is importantly required to obtain ideal information related to tree attributes. Most studies generally used diameter distribution since it could also describe the vegetation structure from the sampling location (Altanzagas et al., 2019; Istrefi et al., 2019; Karyati et al., 2021). Moreover, the diameter is a tree parameter that most accurate to measure. It also has a strong correlation with other tree attributes, such as height, volume, and. Therefore, some studies also reported the diameter is the best variable to represent tree growth biomass (Puri et al., 2013; Lisboa et al., 2018; Abrantes et al., 2019).

According to the results, the mean diameter of 25 sample trees was 16 cm with a minimum of 6.80 cm and a maximum of 25.89 cm (Table 1). The average height of selected trees was 23.78 m with a mean volume of 0.28 m^3. Total above ground biomass varied from 12.68 to 411.94 kg. The highest mean biomass of tree components was found in the stem (118.76±92.65 kg), followed by foliage (4.23±2.77 kg) and branch (4.01±2.70 kg). This finding indicated approximately 90% of biomass from sample trees was accumulated in the stem. Trees generally allocate biomass in stem since it aims to optimize the translocation process for water, nutrients, and photosynthate (Wirabuana et al., 2020). This trend is generally found in every wood species in the different types of forest ecosystems.

Carbon storage

Total carbon storage of *E. urophylla* in dryland ecosystems was highly varied. Our study recorded that the mean carbon storage of *E. urophylla* in the study site was 55.51 kg $tree^{-1}$ with a minimum of 6.34 kg $tree^{-1}$ and a maximum of 184.76 kg $tree^{-1}$ (Table 1).

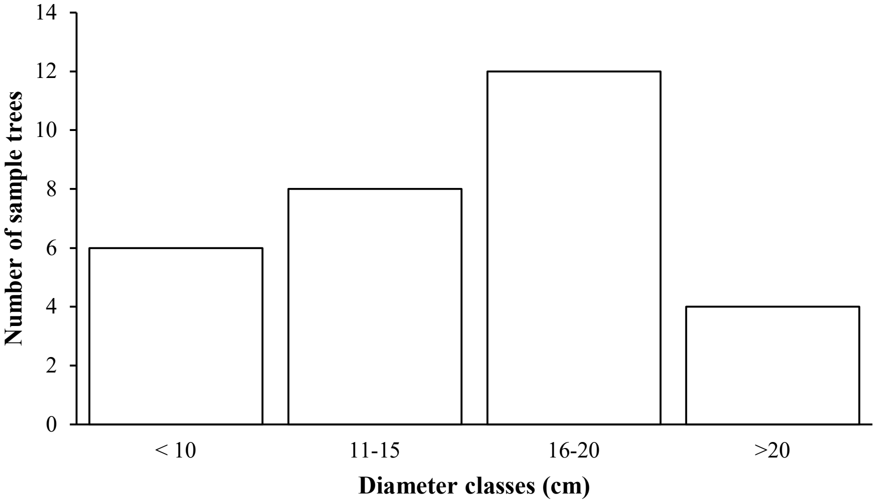

Figure 2. Distribution of sample trees in every diameter class

Similar to the trend of biomass distribution, the majority of carbon storage in *E. urophylla* was accumulated in the stem. Interestingly, this study realized that the carbon storage of branches was slightly higher than foliage even though its biomass was relatively lower. It was caused by the percentage of carbon content in the branch was substantially higher than foliage by a difference of 8.4% (Table 2).

Table 2. The percentage of carbon content in every tree component of *E. urophylla* in the study site.

Tree components	Carbon content (%)			
	Min	Max	Mean	SD
Stem	40.0	50.0	44.1	3.2
Branch	40.0	45.0	42.3	2.0
Foliage	30.0	40.0	34.1	2.9

According to the results, the percentage of carbon content from tree biomass relatively varied in every component. The highest percentage of carbon content was observed in stem (44.1%), followed by branch (42.3%) and foliage (34.1%) (Table 2). This finding was different from previous studies that assumed the percentage of carbon content in eucalyptus biomass around 50% (Latifah et al., 2018; Viera and Rodríguez-Soalleiro, 2019; Wirabuana et al., 2019; Magalhães et al., 2020). In general, the variation of carbon storage in tree species was influenced by certain factors, including age, site quality, and genetics. Carbon storage principally increased along with age due to the influence of tree dimension increment, mainly for diameter (Kohl et al., 2017). It was also supported by our results wherein the relative contribution of the stem to total carbon storage significantly improved along with the diameter (Figure 3). However, the opposite trend was noted in the relative contribution of branch and foliage. Site quality could influence carbon storage since it is related to the land suitability for supporting plant growth and development (Keyser and Zarnoch, 2012). In this context, the plant potentially generated lower performance in poor sites than good sites. Since *E. urophylla* is naturally distributed in the dryland ecosystems, the effect of site quality on its variation of carbons storage in this study location is additive. In addition, the response of trees on-site quality also varied depending on its genetic (King et al., 2013). The different genetic would demonstrate a different response to competition at the stand level (Binkley et al., 2017). Therefore, even though all sample trees were obtained from a similar site, there was a growth variation from every tree sample, particularly for carbon storage.

Energy production

Energy potential in *E. urophylla* trees is naturally coming from the solar energy that is absorbed through the photosynthesis process (Ellison et al., 2017). Then, the energy is converted to biomass as the net primary productivity of trees (Robakowski et al., 2018). When the biomass of *E. urophylla* is burned, its energy would be released as calorific (Ferreira et al., 2017). Thereby, the analysis of calorific value is exceptionally required to calculate the energy production from *E. urophylla*. Interestingly, this study found the highest calorific value of tree components in *E. urophylla* was recorded in foliage (5,252 kcal kg^{-1}), followed by stem (4,408 kcal kg^{-1}), and branch (4,336 kcal kg^{-1}). A higher calorific value indicated the tree components were easier to burn (Chakradhari and Patel, 2016). However, even though it contained the highest calorific value, the energy production in the foliage was considerably lower than stem since it had a lower accumulation of biomass.

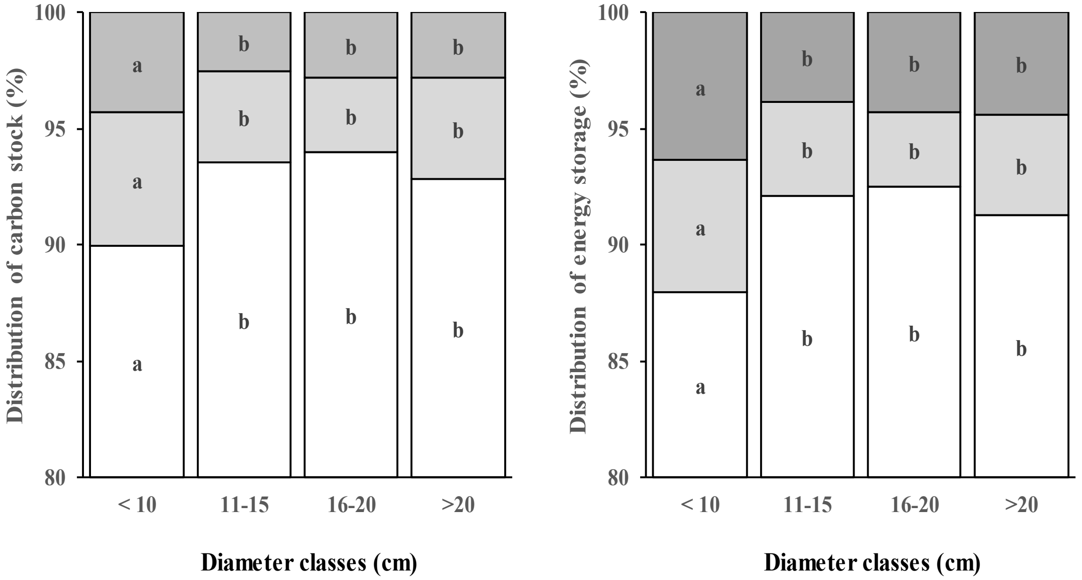

Figure 3. Distribution of carbon stock and energy storage in every tree component at the diameter classes.

Many studies published energy production of tree species was quantified by considering the calorific value and biomass (Magnago et al., 2016; Simetti et al., 2018; Visser et al., 2020). Besides improving carbon storage, higher biomass also increased the potential of energy in tree species. Based on the results, the energy production of *E. urophylla* in dryland ecosystems ranged from 252.56 MJ tree^{-1} to 7,813.30 MJ tree^{-1} (Table 1). It confirmed there was a high potential to utilize *E. urophylla* as a source of renewable energy, particularly in the study site.

Table 3. The calorific value in every tree component of *E. urophylla* in the study area.

Tree components	Calorific value (kcal kg^{-1})			
	Min	Max	Mean	SD
Stem	4,339	4,461	4,408	37
Branch	4,310	4,365	4,336	17
Foliage	5,032	5,534	5,252	134

Conclusion

According to the results, this study concluded that the development of *E. urophylla* in dryland ecosystems shows a meaningful contribution to supporting climate change mitigation and renewable energy development. The average carbon storage of *E. urophylla* at the individual tree level ranged from 6.34 to 184.76 kg tree$^{-1,}$ with the energy production varied from 252.6 to 7,813.3 MJ tree^{-1}. Higher tree dimension demonstrates greater carbon storage and energy production since both parameters have a strong correlation with tree biomass.

Acknowledgements

The authors highly appreciate to Universitas Gadjah Mada that provides the financial support to conduct this research under the scheme of Penelitian Dasar Unggulan Perguruan Tinggi (PDUPT) with having a contract agreement number 1167/UN1/DITLIT/DIT-LIT/PT/2021. The appreciation is also delivered to the institution of Timor Tengah Selatan Forest Management Unit that allows implementing this study in their concession area..

References

Abrantes, K.K.B., Paiva, L.M., De Almeida, R.G., Urbano, E., Ferreira, A.D. and Mazucheli, J. 2019. Modeling the individual height and volume of two integrated crop-livestock-forest systems of *Eucalyptus spp*. in the Brazilian Savannah. *Acta Scientific* 41:1-8, doi:10.4025/actasciagron.v41i1.42626.

Almulqu, A.A., Arpornpong, N. and Boonyanuphap, J. 2019. Biomass estimation and allometric equation for tree species in dry forest of East Nusa Tenggara, Indonesia. *Foresty Ideas* 25:369-384.

Altanzagas, B., Luo, Y., Altansukh, B., Dorjsuren, C., Fang, J. and Hu, H. 2019. Allometric equations for estimating the above-ground biomass of five forest tree species in Khangai, Mongolia. *Forests* 10:1-17, doi:10.3390/f10080661.

Amissah, L., Mohren, G.M.J., Kyereh, B. and Poorter, L. 2015. The effects of drought and shade on the performance, morphology and physiology of Ghanaian tree species. *PLoS One* 10:1-22, doi:10.1371/journal.pone.0121004.

Arora, G., Chaturvedi, S., Kaushal, R., Nain, A. and Tewari, S. 2014. Growth, biomass, carbon stocks, and sequestration in an age series of *Populus deltoides* plantations in Tarai region of central Himalaya. *Turkish Journal of Agriculture and Forestry* 38:550-560, doi:10.3906/tar-1307-94.

Beyene, K. 2016. Assessing univariate and multivariate homogeneity of variance: a guide for practitioners. *Journal of Mathematical Theory and Modeling* 6:13-17.

Binkley, D., Campoe, O.C., Alvares, C., Carneiro, R.L., Cegatta, Í. and Luiz, J. 2017. The interactions of climate, spacing and genetics on clonal Eucalyptus plantations across Brazil and Uruguay. *Forest Ecology and Management* 405:271-283, doi:10.1016/j.foreco.2017.09.050.

Chakradhari, S. and Patel, K.S. 2016. Combustion characteristics of tree woods. *Journal of Sustainable Bioenergy Systems* 6:31-43, doi:10.4236/jsbs.2016.62004.

Cuong, T., Chinh, T.T.Q., Zhang, Y. and Xie, Y. 2020. Economic performance of forest plantations in Vietnam: *Eucalyptus*, *Acacia mangium*, and *Manglietia conifera*. *Forests* 11:1-14, doi:10.3390/f11030284.

Ellison, D., Morris, C.E., Locatelli, B., Sheil, D., Cohen, J., Murdiyarso, D., Gutierrez, V., van Noordwijk, M., Creed, I.F., Pokorny, J., Gaveau, D., Spracklen, D. V., Tobella, A.B., Ilstedt, U., Teuling, A.J., Gebrehiwot, S.G., Sands, D.C., Muys, B., Verbist, B., Springgay, E., Sugandi, Y. and Sullivan, C.A. 2017. Trees, forests and water: Cool insights for a hot world. *Global Environmental Change* 43:51-61, doi:10.1016/j.gloenvcha.2017.01.002.

Ferreira, M.C., dos Santos, R.C., Castro, R.V.O., Carneiro, A. de C.O., da Silva, G.G.C. , Castro, A.F.N.M., de Costa, S.E. L. and Pimenta, A.S. 2017. Biomass and energy production at short rotation Eucalyptus clonal plantations deployed in Rio Grande Do Norte. *Revista Árvore* 41:1-7, doi:10.1590/1806-90882017000500004.

Ghasemi, A. and Zahediasl, S. 2012. Normality tests for statistical analysis: A guide for non-statisticians. *International Journal of Endocrinology and Metabolism* 10:486-489, doi:10.5812/ijem.3505.

Hakamada, R., Hubbard, R.M., Ferraz, S. and Stape, J.L. 2017. Biomass production and potential water stress increase with planting density in four highly productive clonal Eucalyptus genotypes. *Southern Forests: a Journal of Forest Science* 79:251-257, doi:10.2989/20702620.2016.1256041.

Hernández-Ramos, J., De los Santos-Posadas, H.M., Valdez-Lazalde, J.R., Tamarit-Urias, J.C., Ángeles-Pérez, G., Hernández-Ramos, A., Peduzzi, A. and Carrero, O. 2017. Biomasa aérea y factores de expansión en plantaciones forestales comerciales de *Eucalyptus urophylla* S.T. Blake. *Agrociencia* 51:921-938.

Istrefi, E., Toromani, E., Çollaku, N. and Thaçi, B. 2019. Allometric biomass equations for young trees of four broadleaved species in Albania. *New Zealand Journal of Forestry Science* 49:1-14, doi:10.33494/nzjfs492019x51x.

Ju, Y.M., Ann, B.J. and Lee, J. 2016. Comparative analysis of gross calorific value by determination method of lignocellulosic biomass using a bomb calorimeter. *Journal of The Korean Wood Science and Technology* 44:864-871, doi:10.5658/WOOD.2016.44.6.864.

Kalima, T., Malik, J. and Sunarto. 2019. Exploration of rattan species in South Central Timor Regency, East Nusa Tenggara Province. *Jurnal Pro-Life* 6:160-170, doi:10.33541/pro-life.v6i2 (*in Indonesian*).

Karyati, Widiati, K.Y., Karmini, and Mulyadi, R. 2021. The allometric relationships for estimating above-ground biomass and carbon stock in an abandoned traditional garden in East Kalimantan, Indonesia. *Biodiversitas* 22:751-762, doi:10.13057/biodiv/d220228.

Keyser, T.L. and Zarnoch, S.J. 2012. Thinning, age, and site quality influence live tree carbon stocks in upland hardwood forests of the Southern Appalachians. *Forest Science* 58:407-418.

King, G.M., Gugerli, F., Fonti, P. and Frank, D.C. 2013. Tree growth response along an elevational gradient: Climate or genetics? *Oecologia* 173:1587-1600, doi:10.1007/s00442-013-2696-6.

Kohl, M., Neupane, P.R. and Lotfiomran, N. 2017. The impact of tree age on biomass growth and carbon accumulation capacity?: A retrospective analysis using tree ring data of three tropical tree species grown in natural forests of Suriname. *PLoS One* 12:1-17.

Latifah, S., Muhdi, M., Purwoko, A. and Tanjung, E. 2018. Estimation of above-ground tree biomass *Toona sureni* and *Coffea arabica* in agroforestry system of Simalungun, North Sumatra, Indonesia. *Biodiversitas* 19:620-625, doi:10.13057/biodiv/d190239.

Lisboa, S.N., Guedes, B.S., Ribeiro, N. and Sitoe, A. 2018. Biomass allometric equation and expansion factor for a mountain moist evergreen forest in Mozambique. *Carbon Balance and Management* 13:1-16, doi:10.1186/s13021-018-0111-7.

Lu, H., Xu, J., Li, G. and Liu, W. 2020. Site classification of *Eucalyptus urophylla* × *Eucalyptus grandis* plantations in China. *Forests* 11:1-15, doi 10.3390/f11080871.

Lu, K., Bi, H., Watt, D., Strandgard, M. and Li, Y. 2018. Reconstructing the size of individual trees using log data from cut-to-length harvesters in *Pinus radiata* plantations: a case study in NSW, Australia. *Journal of Forestry Research* 29:13-33, doi:10.1007/s11676-017-0517-1.

Magalhães, T.M., Cossa, V.N., Guedes, B.S. and Fanheiro, A.S.M. 2020. Species-specific biomass allometric models and expansion factors for indigenous and planted forests of the Mozambique highlands. *Journal of Forestry Research* 32(333):1-19, doi:10.1007/s11676-020-01156-0.

Magnago, L.M., Arantes, M.D.C., Vidaurre, G.B., Moulin, J.C. and Trugilho, P.F. 2016. Energy estimate and carbon stock in short-rotation eucalyptus stands. *Cerne* 22:527-534, doi:10.1590/01047760201622042209.

Mishra, P., Pandey, C.M. and Singh, U. 2019. Descriptive statistics and normality tests for statistical data. *Annals of Cardiac Anaesthesia* 22:67-72, doi:doi.org/10.4103/aca.ACA.

Oliveira, A.H., Silva, M.L.N., Curi, N., Avanzi, J.C., Neto, G.K. and Araújo, E.F. 2013. Water erosions in soils under eucalyptus forest as affected by development stages and management systems. *Ciencia e Agrotecnologia* 37:159-169, doi:10.1590/S1413-70542013000200007.

Pujiarti, R. and Kasmudjo. 2016. Chemical compositions and insecticidal activity of *Eucalyptus urophylla* essential oil against *Culex quinquefasciatus* mosquito. *Journal of The Korean Wood Science and Technology* 44:494-504, doi:10.5658/WOOD.2016.44.4.494.

Pujiarti, R., Nurjanto, H.H. and Sunarta, S. 2018. Antifungal activity of *Eucalyptus urophylla* oil against *Aspergillus niger* and *Fusarium oxyporum*. *Agrivita* 40:55-62, doi:10.17503/agrivita.v40i1.990.

Puri, L., Meilby, H., Rayamajhi, S., Timilsina, Y.P., Gautam, N.P., Subedi, R. and Larsen, H.O. 2013. Growth and volume based on permanent sample plots in forests managed by communities. *Banko Janakari* 22:11-18, doi:10.3126/banko.v22i2.9194.

Raj, A., Jhariya, M.K. and Bargali, S.S. 2016. Bund based agroforestry using Eucalyptus species: a review. *Current Agriculture Research Journal* 4:148-158, doi:10.12944/carj.4.2.04.

Robakowski, P., Bielinis, E. and Sendall, K. 2018. Light energy partitioning, photosynthetic efficiency and biomass allocation in invasive *Prunus serotina* and native *Quercus petraea* in relation to light environment, competition and allelopathy. *Journal of Plant Research* 131:505-523, doi:10.1007/s10265-018-1009-x.

Saadaoui, E., Ben Yahia, K., Dhahri, S., Ben Jamaa, M.L. and Khouja, M.L. 2017. An overview of adaptative responses to drought stress in *Eucalyptus spp*. *Forestry Studies* 67:86-96, doi:10.1515/fsmu-2017-0014.

Sadono, R., Wardhana, W., Wirabuana, P.Y.A.P. and Idris, F. 2020. Productivity evaluation of *Eucalyptus urophylla* plantation established in dryland ecosystems, East Nusa Tenggara. *Journal of Degraded and Mining Lands Management* 8:2502-2458, doi:10.15243/jdmlm. 2020.081.2461.

Sadono, R., Wardhana, W., Wirabuana, P.Y.A.P. and Idris, F. 2021. Soil chemical properties influences on the growth performance of *Eucalyptus urophylla* planted in dryland ecosystems, East Nusa Tenggara. *Journal of Degraded and Mining Lands Management* 8:2635-2642, doi:10.15243/jdmlm.2021.082.2635.

Sadono, R., Wardhana, W., Wirabuana, P.Y.A.P. and Idris, F., 2021. Allometric equations for estimating above-ground biomass of *Eucalytpus urophylla* S.T. Blake in East Nusa Tenggara. *Jurnal Manajemen Hutan Tropika* 27: 24-31, doi:10.7226/jtfm.27.1.24.

Sato, J.H., de Figueiredo, C.C., Marchão, R.L., Madari, B.E., Benedito, L.E.C., Busato, J.G. and de Souza, D.M. 2014. Methods of soil organic carbon determination in Brazilian savannah soils. *Scientia Agricola* 71: 302-308, doi:10.1590/0103-9016-2013-0306.

Sebei, K., Sakouhi, F., Herchi, W., Khouja, M.L. and Boukhchina, S. 2015. Chemical composition and antibacterial activities of seven Eucalyptus species essential oils leaves. *Biological Research* 48:1-5.

Simetti, R., Bonduelle, G.M., da Silva, D.A., Mayer, S.L.S., Souza, H.P. and de Muniz, G.I.B. 2018. Production of biomass and energy stock for five Eucalyptus species. *Revista Ciência da Madeira - RCM* 9:30-36, doi:10.12953/2177-6830/rcm.v9n1p30-36.

Stavi, I. 2019. Seeking environmental sustainability in dryland forestry. *Forests* 10:1-6, doi:10.3390/f10090737.

Sumardi, Kurniawan, H. and Prastyono, 2016. Genetic parameter estimates for growth traits in an *Eucalyptus Urophylla* S.T. Blake progeny test in Timor Island. *Indonesian Journal of Forestry Research* 3:119-127, doi:10.20886/ijfr.2016.3.2.119-127.

Thompson, A., Davis, J.D. and Oliphant, A.J. 2016. Surface runoff and soil erosion under eucalyptus and oak canopy. *Earth Surface Processes and Landforms* 41:1018-1026, doi:doi.org/10.1002/esp.3881.

Traoré, N., Sidibé, L., Figuérédo, G. and Chalchat, J.C. 2010. Chemical composition of five essential oils of eucalyptus species from mali: *E. houseana* f.v. Fitzg. ex Maiden, *E. citriodora* Hook., *E. raveretiana* F. Muell., *E. robusta* Smith and *E. urophylla* S.T. Blake. *Journal of Essential Oil Research* 22:510-513, doi:10.1080/10412905.2010.9700385.

Viera, M. and Rodríguez-Soalleiro, R. 2019. A complete assessment of carbon stocks in above and belowground biomass components of a hybrid eucalyptus plantation in Southern Brazil. *Forests* 10:1-12, doi:10.3390/f10070536.

Visser, L., Hoefnagels, R. and Junginger, M. 2020. The potential contribution of imported biomass to renewable energy targets in the EU-the trade-off between ambitious greenhouse gas emission reduction targets and cost thresholds. *Energies* 13:1-30, doi:10.3390/en13071761.

Wang, Z., Du, A., Xu, Y., Zhu, W. and Zhang, J. 2019. Factors limiting the growth of eucalyptus and the characteristics of growth and water use under water and fertilizer management in the dry season of Leizhou Peninsula, China. *Agronomy* 9:1-17, doi:10.3390/agronomy9100590.

Wirabuana, P.Y.A.P., Alam, S., Matatula, J., Harahap, M.M., Nugroho, Y., Idris, F., Meinata, A. and Sekar, D.A., 2021. The growth, aboveground biomass, crown development, and leaf characteristics of three eucalyptus species at initial stage of planting in Jepara, Indonesia. *Biodiversitas* 22(5):2859-2869, doi:10.13057/biodiv/d220550.

Wirabuana, P.Y.A.P., Sadono, R. and Jurniarso, S., 2019. Fertilization effects on early growth, aboveground biomass, carbon storage, and leaf characteristics of *Eucalyptus pellita* F.Muell. in South Sumatra. *Jurnal Manajemen Hutan Tropika* 25:154-163, doi:10.7226/jtfm.25.3.154

Wirabuana, P.Y.A.P., Setiahadi, R., Sadono, R., Lukito, M., Martono, D.S. and Matatula, J., 2020. Allometric equations for estimating biomass of community forest tree species in Madiun, Indonesia. *Biodiversitas* 21(9):4291-4300, doi:10.13057/biodiv/d210947.

Yirdaw, E., Tigabu, M. and Monge, A. 2017. Rehabilitation of degraded dryland ecosystems - review. *Silva Fennica* 51:1-32, doi:10.14214/sf.1673.

Yu, F., Van Truong, T., He, Q., Hua, L., Su, Y. and Li, J. 2019. Dry season irrigation promotes leaf growth in *Eucalyptus urophylla* × *E. grandis* under fertilization. *Forests* 10:1-14, doi:10.3390/f10010067.

Zhang, Z.Z., Zhao, P., Oren, R., Mccarthy, H.R., Niu, J.F., Zhu, L.W., Ni, G.Y. and Huang, Y.Q. 2015. Water use strategies of a young *Eucalyptus urophylla* forest in response to seasonal change of climatic factors in South China. *Biogeosciences Discussions* 12(13):10469-10510, doi:10.5194/bgd-12-10469-2015.

Zhou, L., Li, J., Kong, Q., Luo, S., Wang, J., Feng, S., Yuan, M., Chen, T., Yuan, S. and Ding, C. 2021. Chemical composition, antioxidant, antimicrobial, and phytotoxic potential of *Eucalyptus grandis* × *E. urophylla* leaves essential oils. *Molecules* 26:1-12, doi:10.3390/molecules26051450.